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A monthly survey of programs and findings of the International Geophysical Year and the International Geophysical Cooperation–1959 as related primarily to United States programs. The Bulletin *also reports on international programs in geophysics and space science that have grown out of the IGY, and on their results.*

Correlation of Visual and Subvisual Auroras with Changes in the Outer Van Allen Radiation Zone

The following account is based on a more complete report by B. J. O'Brien and J. A. Van Allen of the State University of Iowa, F. E. Roach of the National Bureau of Standards' Boulder Laboratories, and C. W. Gartlein of the IGY World Data Center A for visual auroral data, at Cornell University. The original report appeared in the Journal of Geophysical Research, *September 1960.*

During a severe geomagnetic storm on November 28, 1959, while active visual auroras and a subvisual monochromatic red arc were observed over the northern United States, geiger counters aboard the Explorer VII satellite (1959 Iota) detected anomalous patterns of radiation in the outer Van Allen zone over these same regions. The correlation of these observations constitutes direct evidence of the "dumping" into the upper atmosphere, during times of geomagnetic disturbance, of particles from the "horn" of the outer radiation zone. (See *Bulletin No. 30* for a more detailed discussion of the Van Allen zones of geomagnetically trapped radiation, and *Bulletin No. 36* for additional information on the "dumping" process.)

The visual auroral observations were made by networks of volunteer observers and of all-sky cameras. Both these observing systems were set up as part of the IGY Visual Aurora Program under the direction of the group of auroral physicists at Cornell University.

The subvisual monochromatic arc was detected by photoelectric photometers installed and operated by the National Bureau of Standards at Fritz Peak, Colorado, Sacramento Peak, New Mexico, and Cactus Peak, California, as part of an IGY network of airglow stations. In these arcs, discovered by D. Barbier of the Haute Provence Observatory, France, early in the IGY, radiation at 6300 A (a red line of atomic oxygen) is dominant over the 5577 A radiation (a green line of atomic oxygen) prominent in most visible auroras. (A more-detailed discussion of the 6300 A arcs appeared in *Bulletin No. 36.*)

Explorer VII, which made the correlative radiation measurements in the outer Van Allen zone, was launched under sponsorship of the National Aeronautics and Space Administration on October 13, 1959. At the time of these observations, the satellite's apogee altitude was about 1085 km (675 miles) and its perigee altitude was about 555 km (345 miles). (*Bulletin No. 29* gives additional information on the satellite and its experiments.)

Comparison of Satellite and Visual Auroral Observations

Satellite Observations: Figure 1 shows the counting rate versus time of each geiger tube carried by Explorer VII as the satellite traversed the outer zone traveling northward, and then southward through it again, on its pass over North America between 0355 and 0415 UT on November 27, 1959, when the radiation zone was relatively stable. The pattern for the corresponding pass on November 28 in very nearly the same position in space is also shown, and it is apparent that marked changes have occurred. Finally, to complete the sequence, the corresponding pass on November 29 is shown.

A notable feature of this figure is the very intense radiation peak at 0335:30 UT on November 28. Among many hundreds of samples of radiation in the outer zone measured by Explorer VII, this peak is unique in two respects: it is the narrowest peak seen to date (the satellite traversed it in three seconds), and it contains the softest radiation seen to date, with a ratio of Anton 302 to Anton 112 counting-rates of 27 to 1 compared with the usual outer-zone value of about 14 to 1. (The Anton 302 counter detects X-rays from electrons with energies greater than about 30 kev and the Anton 112 detects X-rays from electrons with energies greater than about 70 kev.)

Visual Observations: All-sky-camera photographs taken at 0336 and 0337 UT on November 28 at Choteau, Montana, by J. G. Robison, show a broad auroral arc at the zenith. A fainter aurora extended at least 0.5° to the south, and a diffuse, medium-intensity arc joins the main arc on the northern side. E. G. Schmidt, a visual observer at Browning, Montana, also observed this feature at 0345 UT. This auroral form began at about 0300 UT, and by 0335 UT it had moved southward about 3.5° of latitude. It continued southward another 1.5° and then changed into a ray structure at about 0455 UT.

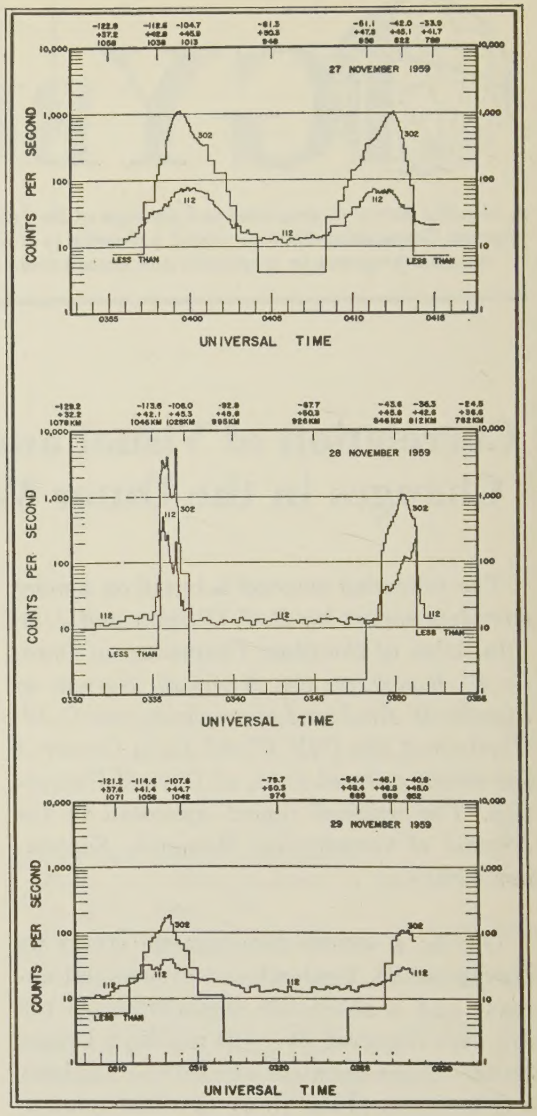

Fig. 1. *True Counting-Rates of Anton 302 and 112 Geiger Tubes on Explorer VII (1959 Iota) During Passes over North America at Roughly the Same Position in Space on November 27, 28, and 29, 1959. Graphs aligned according to time satellite crossed geographic latitude 40° N.*

Correlation: These broad auroral forms were plotted from all-sky photographs to show ground positions of overhead auroras (Fig. 2). The lower edge of the bright arc, as delineated by the visual observer, corresponds to the junction of bright and me-

dium aurora in the figure. The subsatellite locus is also plotted, and this path is projected at right angles to the isocline down the magnetic field lines to give the path projected on the ground. Hatching between the projection lines shows radiation intensities measured by the 302 tube, with three peaks exceeding 3000 counts/sec (see Fig. 1). The downward projections of the anomalous outer-zone structure lie over the auroral forms. Hence, if charged particles detected by the satellite in the structure continued spiraling down the magnetic field lines they would have coincided in space and time with the aurora.

More-detailed discussion of the relationship between the satellite-observed particles and the visible aurora is necessarily tentative, owing to inadequate knowledge of the spectrum and altitude-dependence of particle intensity. Simple considerations of particle energy show that the qualitative correlation established above is also quantitatively plausible.

On the basis of present knowledge, it is reasonable to suppose that the particles detected by the satellite equipment are electrons whose number-energy spectrum rises steeply toward low energies. For a typical particle energy of 50 kev (50,000 electron volts) it is found by laboratory measurement that the counting rate of the 302 counter must be multiplied by a factor of the order of 10^7 to 10^8 to obtain the omnidirectional intensity of electrons. Hence, the energy flux at the position of the satellite is likely to be of the order of 10^4 ergs/cm^2/sec (or greater), or some 5 $\times$ 10^5 times the optical energy emitted in the 5577 A spectral line of an easily visible aurora of 10 kilorayleigh brightness (International brightness coefficient II).

C. E. McIlwain in 1960 found from data obtained by rocket flights into auroras over Fort Churchill, Canada, that the gross efficiency of excitation of atmospheric emissions in the visible region by electrons of similar energy is about 0.2%. Thus, the

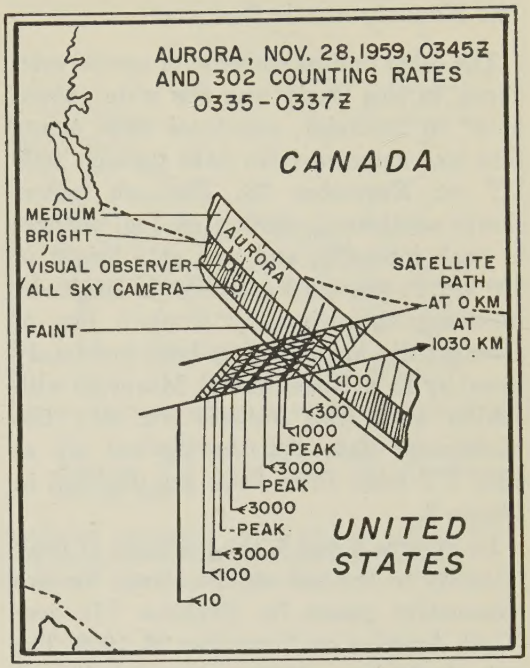

Fig. 2. *Comparison of Positions of Auroral Arc and of Satellite Radiation Measurements in "Horn" of Outer Van Allen Zone over North America at 0336 UT, November 28, 1959. Three heavy lines show projections of counting-rate peaks from satellite orbit down along magnetic-field lines to ground. (<3000 represents counting rate between 1000 and 3000/sec; <1000—300 to 1000/sec; <300—100 to 300/sec; and <100—10 to 100/sec.)*

peak energy flux measured by Explorer VII on this occasion was several hundred times that required to excite the observed aurora. Indeed, this factor may be considerably greater if electrons below the detection threshold of the satellite-borne 302 counter are present.

From the above considerations it appears plausible that the particles in question are in quasi-trapped orbits in the geomagnetic field and are absorbed in the atmosphere after hundreds of latitudinal oscillations (i.e., in a period of time of the order of tens of minutes.) The temporal stability of the arc is an indication that the aurora was not excited by instantaneous dumping of an intense particle flux.

The Monochromatic Red Arc

The other optical emission of special relevance to this study was the wide (about 6°-8° in latitude), sudvisual 6300 A arc that was detected from 0410 through 1000 UT on November 28. The arc moved slowly southward, showed gradual changes in peak intensity, and was at a height of 400 km. It was quite extensive in longitude, following approximately along a line of constant dip angle, as has been previously noted by F. E. Roach and E. Marovich with similar arcs. (See *Bulletin No. 36.*) The photometer data showing the red arc at 0855 UT from Fritz Peak are depicted in Figure 3.

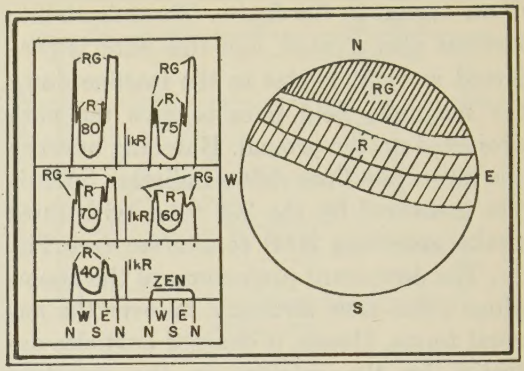

Fig. 3. *Fritz Peak Photometer Record for 0855 UT, November 28, 1959. At right is deduced geographic location of subvisual 6300 A monochromatic red arc (R) and of visual auroral activity (RG) consisting of 6300 A and 5577 A radiation.*

In Figures 4 and 5, the positions of peak intensity of the red arc are shown for two consecutive passes by Explorer VII over North America on November 28, 1959. The latitude thickness of the red arc is indicated roughly by the two lines of constant dip at 66° and 72°. The pertinent satellite path on each pass projected along magnetic lines to the red-arc altitude of 400 km is shown on these maps together with a logarithmic sketch of the Anton 302 counting rate during each pass. (A report by Roach, J. G. Moore, I. C. Bruner, Jr., H. Cronin, and S. M. Silverman, describing how the height of 400 km was estimated, appeared in the November 1960 issue of *JGR.*)

The photometric and satellite observations plotted on the maps were made nearly simultaneously. Plausible extrapolation in longitude of the red arcs on the maps shows a striking positional correlation with the satellite observations. The two classes of observations shown on a map for 0855 UT, when the satellite traveled southeastward along the arc, were coincident in both space and time, and provide even more convincing evidence of their relationship. Both the peak counting rates and the red-arc intensity decreased from pass to pass.

In view of the similarity of the locations and widths of both the red arc and the outer zone (as defined by the 302 counter), and in view of the gradual decrease in intensity of each, the investigators believe that the two are associated. In particular, it appears that the gradual depletion of the outer zone may be due to progressive atmospheric scattering-down and absorption of trapped particles, and that the corresponding energy influx may be the source of energy for the excitation of the 6300 A radiation.

From calculations similar to those used in the discussion of the visual aurora, above, it is estimated that the presumed influx of energy from the detected particles could have maintained a 6300 A arc with an intensity of one kilorayleigh for a period of the order of 10 hours only if the efficiency of excitation is several percent.

Other Relationships and Problems

Observations by R. L. Arnoldy, R. A. Hoffman, and J. R. Winckler with instrumentation in Explorer VI show that there was a very great loss of trapped radiation near the equatorial plane after a sudden geomagnetic-storm commencement in August 1959. As the August event seemed similar in nature to that of November 1959, this evidence may be cited to support the investigators' belief that the decreasing intensity at altitudes of about 1000 km is

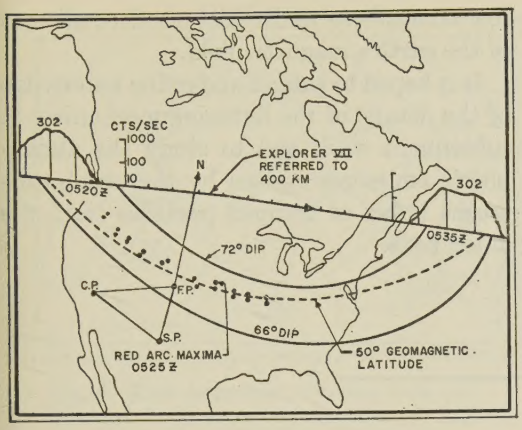

Fig. 4. *Positions of Red-Arc Maxima and Explorer VII Data, 0525 UT, November 28, 1959.*

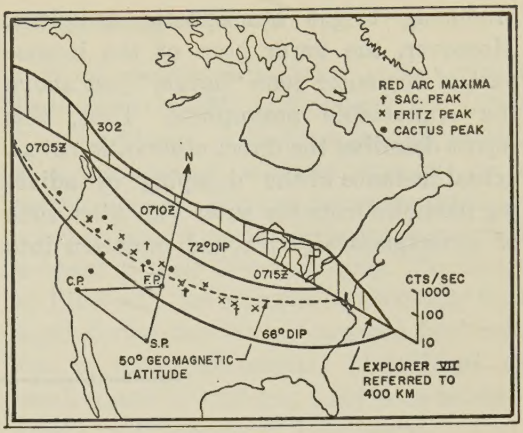

Fig. 5. *Positions of Red-Arc Maxima and Explorer VII Data, 0715 UT, November 28, 1959.*

In both of above figures, satellite data is projected downward to the red-arc height of 400 km; the Anton 302 counting rate is shown on a logarithmic scale on the satellite locus; geomagnetic latitude 50° N is shown; and the 66° and 72° dip lines roughly define the width of the red arc.

due to the absorption of these particles in the atmosphere and not to the other conceivable alternative—gradual upward drift of their mirror points to an altitude above that of the satellite observations.

Many problems remain unanswered in this study. For example, for the occasion investigated there is no knowledge of fluxes of electrons below about 30 kev, and knowledge of the efficiency of energy conversion from electron kinetic energy into optical emissions is insufficient. A further considerable and long-standing problem lies in the fact that, in the red arc, little or no 5577 A radiation was emitted even though the energy required to raise atomic oxygen to the parent level for this spectral line is only 2 ev more than to lift it to the parent level for 6300 A radiation. (G. A. M. King and Roach, in a report appearing in the March 1961 issue of the National Bureau of Standards' *Journal of Research, D—Radio Propagation,* suggest that the effect may be due to a heating of the ionosphere, resulting in an enhancement of the reactions

$$\begin{cases} N_2 + O^+ \rightarrow NO^+ + N \\ NO^+ + e \rightarrow N + O(^1D). \end{cases}$$

This second reaction can excite atomic oxygen to ^1D (2.0 ev) but not to ^1S (4.2 ev) since it is 2.75 ev exothermic.)

Correlation of the red arc with the aurora under the radiation peak at 0336 UT is also uncertain. The intensity of a few kilorayleighs of 6300 A radiation would be insufficient to register either on the human eye or on the all-sky-camera photographs. Previous observations by Roach and Marovich showed conclusively that a 6300 A arc was not merely above a green auroral feature, but indeed on the low-latitude fringe of an aurora containing 5577 A radiation (i.e., was geographically distinct from it). If it is assumed that the 6300 A arc on November 28, 1959, was of a similar type, it would be supposed that the RG area of Figure 3 was seen by the visual observer and the all-sky camera whereas the red arc, R, was not.

Conclusions

Since the early work on geomagnetically trapped radiation, it has been clear that the particles present in the outer Van Allen zone have the potential capability of

producing bright atmospheric emissions. Moreover, the lower horn of the intense part of the outer zone "hovers" just above the appreciable atmosphere. Thus, this report describes the direct observation of an actual instance of the "dumping" of radiating particles from the outer Van Allen zone of geomagnetically trapped radiation into the atmosphere under disturbed conditions of the earth's magnetic field.

It is hoped to extend and refine knowledge of the details of the dumping mechanism in subsequent work and to study the atmospheric emissions excited by the usual, quiescent influx of trapped particles from the outer zone.

Ocean Tide Measurements from Antarctic Ice Shelves Using Gravity Techniques

The following material is taken from a more-detailed report, by Edward Thiel, A. P. Crary, R. A. Haubrich, and J. C. Behrendt, published in the Journal of Geophysical Research, *February 1960. Thiel, Crary, and Behrendt were members of wintering-over parties at Little America and Ellsworth IGY Stations at the time these studies were made, and Haubrich later assisted in analyses of computer data. At present, Thiel is associated with the University of Minnesota, Crary is Chief Scientist for the US Antarctic Research Program, and Haubrich and Behrendt, respectively, are associated with the Scripps Institution of Oceanography and the University of Wisconsin.*

Although the rise and fall of ocean waters along coasts was perhaps one of the first geophysical phenomena studied by man, the measurement of tides in the open ocean remains a difficult problem, as platforms from which such measurements are attempted themselves rise and fall with the tide. Measurements from surface vessels using anchor and line are not sufficiently accurate, and the use of pressure recorders resting on the bottom in deep water involves serious difficulties. It seems likely, therefore, that some new technique may ultimately prove best for tidal measurements at sea.

Gravimetric determinations of the ocean tide were made during the austral midwinter of 1957 at Ellsworth and Little America IGY stations, established on floating ice shelves on opposite sides of Antarctica (see Fig. 6). Ellsworth Station, at 77° 42.6′ S, 41° 08′ W, on the Filchner Ice Shelf, is 2 km from the ice front and 115 km from the nearest land. The station is at an elevation of 42 meters and the ice shelf beneath it is 232 meters thick. The ocean depth below the station, determined by seismic methods, is 792 meters. Little America Station, at 78° 11.9′ S, 162° 16′ W, on the Ross Ice Shelf, is 5 km from the ice front and 2 km from an embayment in the ice shelf, Kainan Bay. It is 60 km from Roosevelt Island, the nearest land. The ocean floor at this location is 578 meters below sea level, the station elevation is 44 meters, and the ice shelf is 259 meters thick.

The vertical movements of the ice shelves observed with gravity meters are of two general types: (i) the rise and fall of the shelf in response to ocean tides, and (ii) a

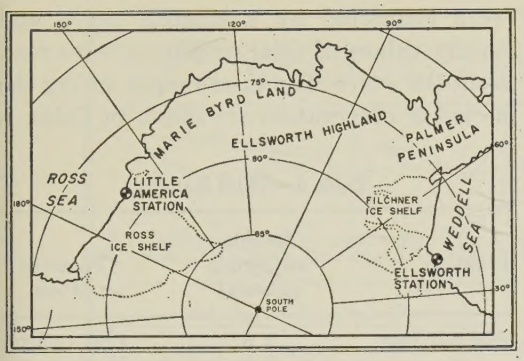

Fig. 6. *West Antarctica, Showing Ross and Filchner Ice Shelves and Locations of Little America and Ellsworth IGY Stations.*

high-frequency, oscillatory motion of nontidal origin, with periods ranging from about 15 to 50 seconds.

Oscillations at the Ice Front

Oscillations similar to those observed in the Antarctic were previously noted by Crary and others in the Arctic Ocean during gravity meter readings on pack ice 2 meters thick and on a floating ice island 60 meters thick. It is believed that these oscillations are of oceanic origin and are influenced by the amount of ice cover. At Little America Station, when there was extensive open water offshore in February 1958 (austral summer), the tidal oscillations were too large to be read on the instrument scale; by April, however, when very little open water remained in the Ross Sea, the amplitude of the oscillations had decreased greatly and the scale could again be read easily.

These high-frequency vibrations damp out fairly rapidly inland from the ice front. At a distance of 10 or 15 km from the edge, though still on the floating shelf, the gravity meter can be read as at a land station. Figure 7 illustrates the decrease in amplitude between measurements made 1.3 and 15.4 km from the ice front in October 1957, as the Ellsworth oversnow traverse team proceeded inland from the station.

Ocean Tides

Tidal observations were made during June and July 1957 at Ellsworth and Little America Station, with Frost gravity meters, at approximately bi-hourly intervals for a month. The two Frost meters were specially selected for the oversnow traverse program because of their low drift rates. The meter at Ellsworth, for example, drifted only 0.93 mgal during the 81-day summer field season, or 0.34 mgal/month. (A milligal, or mgal, equals 1/1000 gal; a gal is an acceleration due to gravity of 1 cm/sec^2.)

In addition to the small instrument drift, a change of gravity was expected to result from the slow northward (seaward) movement of the station during the time of the tidal study. The northward component of movement at Ellsworth, as determined by celestial navigation, is 1.25 km per year. According to the International Gravity Formula, this change in latitude will result in a 0.35 mgal decrease in gravity during the course of one month. However, because instrumental drift and physical drift of the station are both small, and may be expected to have opposite signs, no correction for them was made in reducing the gravity data.

The change of gravity with elevation in air at the surface of the earth is 0.3086

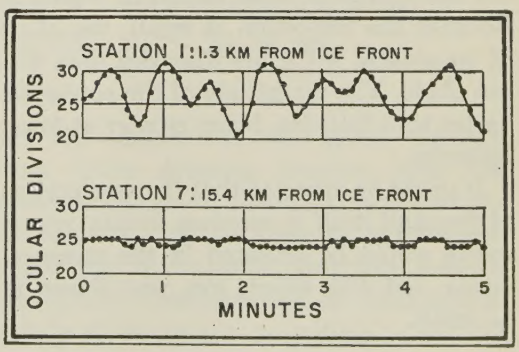

Fig. 7. *Gravity Meter Record, Showing Oscillations Near Seaward Edge of Filchner Ice Shelf and Decrease in Amplitude with Distance from Ice Edge, October 1957.*

mgal/meter. However, in the present case, the gravity meter does not simply move up and down in air; it is also necessary to apply a correction to allow for the changing thickness of the water column.

Figures 8 and 9 are plots of tidal fluctuations in the Weddell and Ross Seas, respectively, during portions of June and July 1957. The tidal variations, in meters, were computed using a formula to convert gravity variations to height. The mean gravity value for the month of observation was equated to zero so that tides could be measured as deviations, in meters, from this mean. The tidal heights, in meters, were found to be equal to 3.7653 × the gravity deviation in mgals.

In the gravimetric method, the tide is measured with respect to the center of the earth. The conventional tide, on the other hand, as measured by a tidal gage on a coast, is the change of the sea surface with respect to the adjacent rock surface, and the rock surface is subject to "earth tides" resulting from the varying attractions of the sun and moon on the solid earth. In principle, therefore, if the gravimetrically determined tide is to be compared with the conventional tide, a correction for earth tides is necessary.

The Weddell Sea data were corrected for earth tides and the magnitude of this correction is indicated by the dotted line for the third week of observation in Figure 8. Because the correction is small, the effort of computing it for the Ross Sea data was not made. The magnitude of the correction varies with latitude, being greater at lower latitudes.

It might be expected that the acceleration of the shelf itself in response to tidal movements would be reflected in the measurements, but this effect, too, was shown to be small.

Analysis

In Figures 8 and 9, the measurements are indicated by dots. These control points were connected by a smooth curve and hourly values of tidal amplitude were read from the curve. The tidal ranges during the period of observation are shown in Table 1.

Table 1—Tidal Ranges

Location	Double Amplitude (meters)	Phase of Moon
Weddell Sea	0.6	Last quarter
	3.2	New moon
	0.9	First quarter
	2.2	Full moon
	0.8	Last quarter
Ross Sea	1.4	Full moon
	0.3	Last quarter
	1.3	New moon
	0.4	First quarter
	1.2	Full moon

From the hourly data, the amplitude and phase were computed for the more-prominent tidal components. For each component, the number of hourly observations was chosen so that the time-length of the record would be close to an integral multiple of the period of that component. The tidal amplitude of several harmonics on either side of this particular harmonic were also computed to provide an estimate of the noise level inherent to the data.

Analysis of this data shows that the principal differences between Weddell Sea and Ross Sea tides are: (1) the Weddell Sea tide may be classed as a mixed tide, having both diurnal and semidiurnal components, whereas the Ross Sea tide is diurnal; and (2) the tidal amplitudes are larger in the Weddell Sea than in the Ross Sea, a fact possibly related to the shape of the basins south of the two stations.

Tidal Currents

On July 4, 1958, oceanographic studies were made at Kainan Bay, near Little America Station, including measurements with an Ekman current meter, during a 6-hour interval at depths of 300 and 400

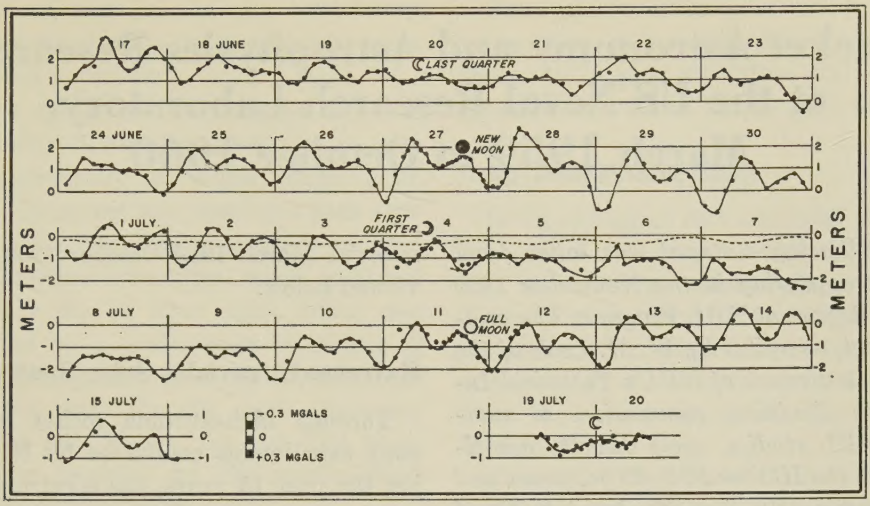

Fig. 8. *Gravity Meter Record of Weddell Sea Tides, June 17–July 19, 1957.*

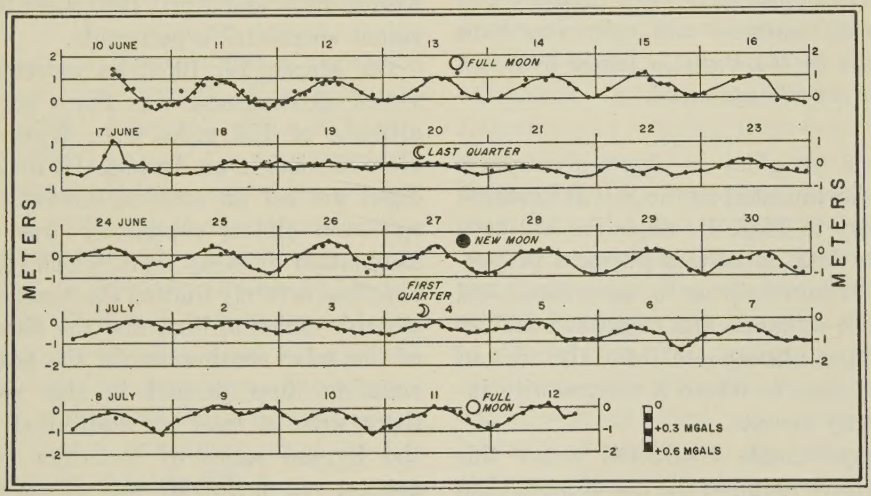

Fig. 9. *Gravity Meter Record of Ross Sea Tides, June 10–July 12, 1957.*

meters. Simultaneously, gravity measurements were made at Little America with the hope of obtaining a correlation between tidal currents and vertical shelf movements, from which the north-south dimension of the shelf might be calculated. Computations based on these measurements gave a north-south dimension of the ice shelf of 1000 km. By comparison, the actual distance from Little America Station, near the northern margin of the shelf, to the southern extremity of the Ross Ice Shelf is 840 km. It may be concluded, therefore, that the gravimetric determination of tidal amplitude is of the proper magnitude to account for the observed tidal current.

Rocket Astronomy and Astrophysics Research at the US Naval Research Laboratory, March 1959 to October 1960

The following material was taken from a report appearing in the November 1960 issue of Report of NRL Progress. *The original report, compiled by W. M. Leak of the Periodicals Branch of NRL's Technical Information Division, summarizes a number of NRL studies, some directly associated with the IGY or IGC-59 programs and others sufficiently closely related to be of interest to* Bulletin *readers. Subsections dealing with studies already reported in previous* Bulletins *have been condensed in the present treatment and references have been made to the* Bulletin *issues in which the fuller reports appeared.*

A basic program in upper-atmosphere physics was initiated by the Naval Research Laboratory in 1946. Its objective has been to obtain data on certain physical properties that would help us to understand and explain the dynamic and complex behavior of the upper atmosphere from altitudes of about 50 miles to where it merges with interplanetary space.

The experiments conducted under this program have required the use of more than two hundred rockets, including rocket-launched satellites, to carry appropriate scientific instruments for making astrophysical and astronomical measurements directly in the regions of interest or to collect data on some of the brief and elusive physical and chemical processes known or suspected to be taking place. Almost without exception, each experiment has contributed significant results that not only advanced knowledge of the physics of the atmosphere but also helped to launch the current era of space exploration. Major results of the experiments conducted in the interval March 1959–October 1960 are reviewed below.

Extreme-Ultraviolet Solar Spectra

Through high-altitude rocket spectroscopy experiments conducted by NRL during the past 15 years, the spectrum of the sun has been mapped progressively to ever shorter wave-lengths and with constantly improved resolution. Those conducted in March 1959 and April 1960 were the most recent successful experiments.

On March 13, 1959, an extreme-ultraviolet spectrograph was flown to a peak altitude of 123 miles over White Sands, New Mexico, in an Aerobee-Hi rocket. The flight yielded an extreme-ultraviolet solar spectrum almost completely free of contamination by stray light, which for a long time has severely limited the number of detectable emission lines and the observation of the solar continuum. Of the nearly 100 emission lines present in this spectrum, there were at least six additional lines of the Lyman series of hydrogen (Lyman-gamma not included) and about 60 lines that had not been observed previously in the solar spectrum.

Although the spectrograph covered the wavelength range of 500 A to 2100 A (it was more efficient in this range than spectrographs employed in previous successful flights because of improved surface coatings of higher reflectance), the shortest wavelength observed was the HeI line at 584.3 A. Among the new lines identified were those produced by NeVIII, MgX, OII, OIII, OIV, OV, NII, NIII, SI, SVI, and others. The discovery of the NeVIII lines near 800 A is the first direct proof of the

existence of neon in the sun. Still better spectographic results were obtained in a subsequent experiment.

In the spring of 1960 (April 19), the first doubly-dispersing spectrograph was flown successfully at White Sands in an Aerobee-Hi rocket that reached a peak altitude of 130 miles. This experiment resulted in an extreme-ultraviolet solar spectrum completely free of stray light, which was eliminated by a predisperser consisting of a diffraction grating to throw the spectrum of the sun onto the slit, with dispersion along the slit. Hence, for the first time, everything recorded by the spectrograph was real solar emission.

Nearly 200 intense emission lines were observed in the new spectrum, and most of these have been identified. They are lines produced by the abundant elements in the sun through sulphur, in stages of ionization as high as the eleventh. The resonance lines of SiXII (eleventh stage of ionization) at 499.3 A and 521.1 A were the shortest photographed; they require the greatest energy for excitation in the extreme-ultraviolet spectrum of the sun and originate in the corona. In addition, 11 lines of the Lyman series of hydrogen were present (including Lyman-gamma, which is very weak because of intense absorption of this wavelength by atmospheric molecular nitrogen), and the Lyman continuum could be followed to approximately 800 A.

For the first time, the spectrum shows the continuum of the sun from 1500 A to 1000 A, where it is distinguished by the absence of the Fraunhofer lines (dark lines of solar absorption spectrum) that characterize the spectrum at longer wavelengths. Conspicuous within the continuum were absorption bands attributable to the discharge of water vapor from the rocket during flight. Quantitative data on the amount of water vapor surrounding the rocket and on the amount of atmospheric modular nitrogen above the trajectory peak will be obtained from a study of the spectra.

The extreme-ultraviolet solar spectroscopy program is continuing in an effort to obtain still higher resolution and to extend the spectrum to still shorter wavelengths.

Solar-Disk Photography

In the springs of 1959 and 1960, the Naval Research Laboratory succeeded in obtaining, respectively, extreme-ultraviolet and X-ray photographs of the sun. The pictures were taken with cameras developed at NRL and flown in Aerobee-Hi rockets launched from the White Sands Missile Range in New Mexico.

Ultraviolet Photographs: Ultraviolet photographs were obtained by a specially designed camera carried on the March 13, 1959, flight mentioned above. The images showed that Lyman-alpha is emitted with increased intensity over plage regions of the sun, as are the solar radiations produced by calcium-K and calcium-H; the enhanced Lyman-alpha emission areas match the calcium plage pattern in detail but are greater in contrast. This increase in contrast and in coarseness of detail with decreasing wavelengths is consistent with the three-dimensional nature of the solar atmosphere. The stormy appearance of the solar atmosphere at the Lyman-alpha radiation level is in agreement with the picture of ascending columns of turbulent gas, spreading, combining, and merging as they stream out of the sun. Eventually traces of these gases reach the earth. Occasionally, during periods of great solar activity, these gases produce auroras and magnetic storms and disrupt radio communications. (A more-detailed account of this experiment appears in *Bulletin No. 23.*)

An image of the sun in the light of the Lyman-beta radiation of hydrogen is among the objectives of similar experiments planned for the near future.

X-Ray Photographs: A pinhole camera ($6 \times 4 \times \frac{3}{8}$ inch) was used to obtain the first photograph of the quiet sun in its X-ray emission, as X-rays cannot be focused

by lenses or mirrors in the manner of visible or ultraviolet light. The 0.005-inch pinhole was covered with a thin plastic filter, opaque to visible light but partially transparent to soft X-rays. Wavelengths effectively transmitted were in the range 20 A to 60 A. The camera was mounted on a biaxial pointing control that aimed it at the sun throughout the rocket flight. The image on the film at the back end of the camera was only 0.1 inch in diameter, and, though the image was badly smeared in azimuth because of the rotation of the pointing control, the most interesting features of the photograph (Fig. 10) were preserved.

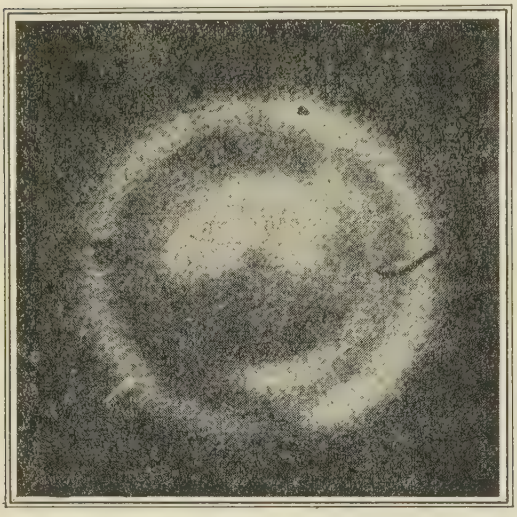

Fig. 10. *X-ray Photograph of the Solar Disk.*

The photograph shows the sun to be rimmed by a bright X-ray halo, and several intense spots of bright X-ray emission appear on the disk. As in the Lyman-alpha photographs, at each region of brilliant X-ray emission is a bright visible plage of calcium light. Two bright plage areas on the west limb and a bright plage in the northeast quadrant account for virtually all of the X-ray emission. Densitometry of the X-ray image indicates that the intensity corresponding to the brightest plage region is about 70 times that from the weakest region of the background. The origin of most of the X-ray emission is in active solar regions, believed to be coronal condensations overlying the plage formations, rather than in a uniform undisturbed corona. The brightest X-ray source in the photograph would require a coronal condensation eight to nine times the density of the undisturbed corona.

Lyman-Alpha Profile

High-resolution spectra of the Lyman-alpha line of hydrogen radiation from the sun were obtained successfully on July 21, 1959, and again on April 19, 1960. The spectra show a broad emission profile (Figure 11) with wings extending a distance of 1 A to either side. Across the top of the profile is a broad, shallow, central reversal similar to those present in the H and K lines of calcium and in the emission lines of the magnesium double (MgII) near 2800 A. In the center of each spectral image is a narrow, deep absorption core; the corrected half-width of the core ranges from 0.025 A to 0.04 A, which corresponds to a Doppler width for hydrogen at a temperature of 800°K to 2100°K.

The shape of the Lyman-alpha emission profile indicates that hydrogen atoms continue to exist in the sun far out in its chromosphere, where the electron density is between 2×10^9 and $3 \times 10^{10}/cm^3$ and the temperature is of the order of 100,000°K. Farther out, as the temperature rises still more, there are no un-ionized atoms left—only protons and electrons, which then "boil off" into space. This forms the "solar wind" that reaches the earth a day or two later and becomes trapped in the Van Allen belts of geomagnetically trapped radiation, discovered with satellites during 1958. From the dimensions of the absorption core produced by neutral atomic hydrogen, it is estimated that a column of 1-cm^2 cross section lying between the sun and the 60-mile level of the terrestrial atmosphere must contain about 3×10^{12} neutral hydrogen atoms.

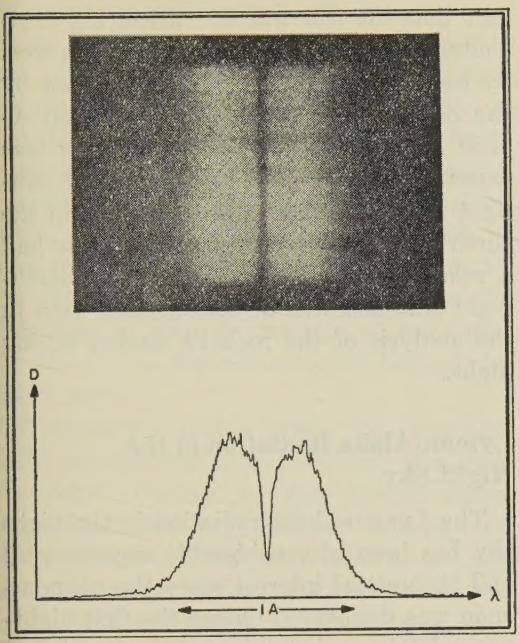

Fig. 11. *High-Resolution Spectral Image of the Lyman-Alpha Line and Its Microphotometer Tracing. The absorption core is the dark area in the very center of the spectral image.*

Night Airglow

It has been known for many years that a major portion of the light from the night sky originates in the earth's upper atmosphere. Information gained from ground-based observations has contributed greatly to studies of upper-atmospheric composition and the radiation processes that result in the airglow emissions, but the results of attempts to determine altitude distributions from ground-based observations have been unreliable. Since altitude information is of vital importance to a comprehensive study of the airglow mechanisms, a program was instituted by NRL in 1955 to measure directly the altitudes of the night airglow emissions by means of rocket-borne photometric equipment. A night airglow rocket flown on November 6, 1959, to an altitude of 140 kilometers, carried a number of photometers which yielded data on several spectral ranges of the airglow emissions.

The altitude of the maximum luminosity of the 5577 A green line of OI was determined to be 97 kilometers, in agreement with the results of earlier experiments. The maximum luminosity of radiation near 2650 A, presumably from the Herzberg bands of molecular oxygen, occurred at an altitude of about 98 kilometers, also in agreement with previous results.

Measurements of the (0–0) atmospheric band of molecular oxygen indicated an emission layer extending from 80 to 100 kilometers, with maximum emission at about 93 kilometers. The intensity of this radiation, which is self-absorbed in the atmosphere and does not reach the ground, was about 3700 rayleighs (self-absorption considerations neglected).

Two photometers were employed specifically in an attempt to measure the infrared emission of OH. The first had a filter of 180 A half-width centered at 7280 A to admit the (8–3) band. The second covered the wavelength range of 7500 A to 1 micron, approximately, and included many strong bands of OH. Data from both photometers indicated that at least three-fourths of the emitting layer was located between 75 and 95 kilometers. Continuum radiation near 5400 A was found to be concentrated at an altitude between 100 and 105 kilometers.

Ultraviolet Nebular Glow and Stellar Photometry

The ultraviolet nebular glow was discovered by NRL scientists in 1957. The discovery was made with a battery of ultraviolet-sensitive Geiger counters, flown in an Aerobee rocket, looking out through narrow collimators (about the size of hypodermic needles). These counters covered the wavelength interval from about 1225 A to 1350 A. Data collected with these instruments indicated that extensive glow regions surrounded all of the early type blue stars, the simplest case being alpha-Virginis. The nebulosity surrounding alpha-Virginis appeared almost circularly distributed out to

10° from the star, with an average surface brightness of 5×10^{-4} erg/cm^2/sec.

Two recent attempts to refine these early measurements have thus far not succeeded in establishing the spectrum of the nebulosity or its geometrical distribution, even with crude resolution. The first occurred on the night of November 6, 1959. In that experiment, an ion chamber with a spectral range of 1230 A–1350 A was mounted at the focus of a single, four-inch, ultraviolet telescope (the first ever used in a rocket astronomy experiment) and flown to a peak altitude of 88 miles above White Sands. The results indicated no bright luminosities more than 4° in width and showed a number of point sources lower in far-ultraviolet intensity than anticipated. It was suspected that differences in detector short wave cutoffs may have been responsible for the disagreement with results from the 1957 experiment.

The next experiment, conducted on May 26, 1960, consisted of a flight of eight 6-inch ultraviolet telescopes, with detectors covering the interval 1050 A–1550 A, three of which accurately controlled short wave cutoffs between 1217 A and 1225 A. Unfortunately, because of sparking, only two telescopes (1280 A–1350 A and 1350 A–1550 A) yielded data. In the 1350 A–1550 A region, more than fifteen B-type stars were observed. Each of these, within the limits of the angular resolution of the instrumentation, appeared as a point source with no associated nebulosity. These same stars were observed simultaneously in the spectral band 1280 A–1350 A.

Again the observations disagree substantially with the results of the 1957 experiment. Until additional data are obtained from future flights, conclusions concerning the last two experiments are considered somewhat tentative. It can only be stated that the nebulosity does not extend beyond 1285 A.

An interesting phenomenon observed in the flight record of the May 1960 experiment merits a brief comment. Despite the fact that the sun was 22° below the horizontal, a strong glow was seen in the west by the 1280 A-1350 A detector but not by the one covering the interval of 1350 A-1550 A. It is believed that this glow was caused by the resonant scattering of sunlight near 1300 A by atomic oxygen in the earth's atmosphere. This western glow had a relatively sharp boundary on its earthward side and was of considerable help in the analysis of the rocket's motion during flight.

Lyman-Alpha Radiation in the Night Sky

The Lyman-alpha radiation in the night sky has been of considerable experimental and theoretical interest since the phenomenon was discovered during the first nighttime NRL rocket-astronomy experiment conducted in 1955.

Despite this early discovery, the origin of the Lyman-alpha glow has not been clearly demonstrated. It seems clear that a major portion of the glow is due to resonant scattering by atomic hydrogen within a geocorona, but still unknown is whether the atomic hydrogen responsible for the glow comes entirely from the earth or whether a substantial portion is interplanetary in origin.

An experiment conducted on January 14, 1960, yielded additional information which, though incomplete and not wholly understood, sheds further light on the problem. A Lyman-alpha detector, utilizing an ionization chamber filled with nitric-oxide gas and fitted with a lithium-fluoride window, was flown in a Javelin rocket launched from Wallops Island, Virginia. The effective spectral range of the detector was approximately 1050 A to 1350 A, and telemetered records from the detector were obtained over an altitude range of 350 to 1120 kilometers. The results showed that the overhead brightness decreases with altitude, the intensity at 1000 kilometers being perhaps 80% that at 300 kilometers; this behavior implies an

appreciable contribution from scattering of solar Lyman-alpha by geocoronal hydrogen. Whether this terrestrially-scattered component is or is not a major fraction of the Lyman-alpha observed at night, however, can be ascertained only by conducting experiments at altitudes still higher than 1120 kilometers. One such experiment is planned for a future deep space probe, to be equipped with a 10-inch Lyman-alpha telescope to scan the vicinity of the earth as the probe travels outward beyond 10 earth radii.

Telemetry records from the January 1960 experiment also indicated a strong "auroral" feature of the Lyman-alpha emission, with an apparent intensity of about 0.0012 erg/cm^2/sec/ster. The auroral feature may be attributed either to emission of molecular nitrogen or molecular oxygen. This conclusion is supported by unpublished data from an NRL rocket experiment conducted in the northern auroral zone (Fort Churchill, Canada) about four years ago (November 1956). On that occasion, roughly equivalent energy was recorded in the two spectral regions of 1220 A-1350 A and 1100 A-1350 A.

Solar Flares

One of the forms of solar activity that produces familiar terrestrial effects (geomagnetic storms, radio blackouts, etc.) is the flare, a sudden, short-lived brightening of the solar surface in the neighborhood of sunspots. A medium-sized flare may release an energy equivalent to millions of H-bombs, yet the mechanism of this process is not well understood. Observations of the X-ray and ultraviolet spectra of flares were started at NRL in 1956 in an effort to learn the nature of the flare phenomenon.

Rocket Studies: Accumulated evidence from instrumented rockets flown during solar flares in 1956 and 1957 showed that the total solar Lyman-alpha emission was not greatly affected by individual flares; in contrast, a considerable increase in solar X-ray emission was observed.

During July, August, and September 1959, twelve Nike-Asp rockets instrumented with photon counters, ion chambers, proportional counters, and scintillation counters to cover the range 44 A-50 A, 8 A-20 A, 2 A-8 A, and 6 A-0.1 A were launched from Point Arguello on the Pacific Missile Range. Seven produced data of geophysical interest; four of these were launched during quiet sun conditions, and three were launched during class 2+ solar flares.

Telemetry records of the data indicate substantially greater X-ray fluxes throughout the spectrum during solar flares than the values indicated for quiet-sun conditions. For example, the average background flux of soft X-rays was 0.74 erg/sec^2/cm, whereas the upper limit of values during solar flares was 9.8 erg/sec^2/cm, which is more than 10 times greater than the average background flux. The ratio of the intensity of X-rays in the 8 A-20 A region to the intensity of those in the 2 A-8 A region changed from one firing to another; a ratio of 23 was obtained for two flights during quiet-sun conditions, 7 for one flight during a bright surge prominence, and 6 for a flight 11 minutes past the peak brilliance of a class 2+ flare. The ratios indicate not only an increase in the intensity of the radiation in these wavelengths during a flare or active prominence but also a hardening of the X-ray spectrum. It appears, therefore, that the hardness of the spectrum plays a more important role than the total flux in accounting for the associated sudden ionospheric disturbances.

Another result was the discovery of extremely energetic X-rays during the most active phases of three class 2+ solar flares. Measurements in connection with the three flares revealed the presence of X-rays with quantum energies as high as 125,000 electron volts. If this radiation were thermal in origin the required temperatures in the solar atmosphere or corona would be as

high as 100,000,000°C. Previously, the most energetic solar flare radiations actually detected were of the order of 6000 to 7000 electron volts, which correspond to temperatures in the solar atmosphere of about 10,000,000°C. (Additional information on this experiment, named "Sunflare," is contained in *Bulletin No. 32.*)

Satellite Studies: Now in orbit around the earth is an NRL satellite (1960 Eta-2) containing ionization chambers (X-ray and Lyman-alpha) similar to those flown in rockets for studying emissions accompanying solar flares. It was carried aloft in piggyback fashion (atop the Navy's Transit II-A navigational satellite) by a Thor-Able-Star rocket launched from the Atlantic Missile Range, Cape Canaveral, Florida, on June 22, 1960. The ionization chambers are making continuous measurements of solar emissions in the two instrumented wavelength bands. Numerous telemetry records have been collected since 1960 Eta-2 was launched, and the progress of data analysis has now begun to reveal some of the results.

For example, on August 6, 1960, the NRL solar radiation satellite caught the early stages of a class 1+ solar flare, which lasted for 18 minutes and was accompanied by sudden ionospheric disturbances. One minute after the start of the flare, short-wave radio signals began to fade. Two minutes later, cosmic radio noise, which normally penetrates the ionosphere, also began to fade. At this point, the telemetry record showed clearly an increase in solar X-rays. Another minute later, a burst of solar radio noise was recorded (at a ground station) that persisted for two minutes, during which time the X-ray flux rose to a very high level and remained very intense after the radio noise subsided. When the satellite passed out of tracking range, the X-ray flux was still strong, but records of the next orbit around the earth, two hours later, showed that the sun was completely calm again, with no evidence of enhanced X-ray emission. Throughout this sequence of events there was no measurable increase in the flux of Lyman-alpha emission.

Thus, the Laboratory's 1960 Eta-2 satellite is providing, for the first time, a reliable time history of solar radiations and the kind and quantity of data long desired and needed for correlating these solar emissions with their terrestrial atmospheric effects. (See *Bulletin No. 42* for further discussion of this experiment and for details of the satellite's orbit and instrumentation.)

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